# Present Status of the Project of Active Phased Array Antennas in Japan and Their Current Achievements


#Tadashi TAKANO+#, Yasuhiro KAZAMA+, Shigeo KAWASAKI++,
Hiroshi TOSHIYOSHI *, Hirokazu IKEDA+, Tamotsu SUDA**
+ Japan Aerospace Exploration Agency, ++Kyoto University
*University of Tokyo, **Japan Radio Co.,Ltd., #Nihon University

e-mail: ttakano@ isas.jaxa.jp (Tadashi TAKANO)


## 1. Introduction

The APAA Project started in 2006 in order to exploit active phased array antennas for practical applications and eventually to encourage the utilization of, so called, high microwave bands [1]. The year of 2007 is the final period focused on the research activities rather than the developmental activities so that the R & D results should be summarized. This paper describes the present status of the project with a view on the final goal, and the achievements made in our R & D activities.

## 2. Significance of 2007 year in the total R&D period

In 2006, the frequency of K-band was selected for system realization in the subsequent years. Also satellite communications were chosen among many applications.

Before the start of 2007, the research objectives were imposed for each research subgroup as follows.

(1) Antennas
  a. To manufacture an array antenna with 10 low profiled elements with an array gain of 9 dB in the partial drive technique[2].
  b. To clarify the wiring method between elements and the allocation method of active circuits.

(2) Monolithic Microwave Integrated Circuits (MMIC)
  a. To realize MMIC amplifiers with the efficiency of 40 % and noise factor of 4dB.
  b. To study the integration method of circuits and element antennas.

(3) Phase shifters and switches of Radio Frequency-Micro Electro Mechanical System (RF-MEMS)
  a. To realize RF-MEMS switches with a size of 2 mm square and a loss of 1 dB/bit.
  b. To realize 4–bit phase shifters with a loss of 4 dB using RF-MEMS technology.

(4) Integration of the total APAA
  a. To establish the evaluation method of APAA
  b. To develop an algorithm and circuits for beam control of a partially driven array antenna.

(5) Systems
  a. To design communication equipment on a car with a 60 cm diameter and a 5 cm thickness.
  b. To investigate the market of satellite communications for ships.

The items (1), (2) and (5) are pursued by JAXA, Kyoto University and Japan Radio Company (JRC), respectively. The items (3) are carried out by the University of Tokyo and Kyoto University , and the items (4) by JRC and JAXA.

## 3. Device research results

### 3.1 Antennas

Formerly, element antennas with a pencil beam are assumed in a partially driven array antenna. [3]. But we devised element antennas with a conical beam which has the main lobe in the elevation angle of several tens degrees [4]. The structure is shown in Fig. 1, and may be called a vertical strip dipole.

The radiation pattern of the element antenna is shown in Fig. 2. The measured and simulated patterns agree well each other. The main beams point to 42 deg. and 53 deg. away from the boresight in E- and H-planes, respectively.

The arrayed elements are shown in Fig. 3. Eight elements out of 19 elements are passive or of mere wires. The beam scan characteristics were simulated in relation to the driving of phase shifters, and are almost the same as those of a fully driven array antenna.

This kind of radiation patterns are beneficial to communicate with a satellite in a low elevation angle without a significant link degradation in the boresight. The gain at angles lower than 55 deg. is estimated to be almost equal to the gain of an array antenna of fully driven elements with pencil beam pattern with a 1 dB penalty.

### 3.2 MMIC amplifiers

High power amplifiers (HPA) and low noise amplifiers (LNA) were designed in the laboratory and manufactured by foundries. The HPA is composed of 3 stages of amplification with chips shown in Fig.4. The power conversion efficiency of 42% has been achieved at 5.8 GHz. In the measurement, the gain was 11 dB, and the output power was 25 dBm [5][6].

The LNA is also composed of 3 stages of amplification, as shown in the block diagram of Fig.5. The noise factor of 1.5 dB has been achieved at 7 to 14 GHz with the gain of 30 dB. This value is a world –record, and sufficient to realize an APAA system.

### 3.3 Phase shifters and switches of RF-MEMS

A novel structure of a RF-MEMS switch was proposed and designed, where the microwave transmission part is separated from the actuator part [7]. The switch is a single pole double throw (SPDT) type, as shown in Fig.6. The measured loss at 5.8 GHz was 2 dB per bit which is larger than the computed loss. That may be due to incomplete modeling of a multi-layered co-planar line. The voltage for driving an actuator should be 40 V.

In K-band, the RF-MEMS switch has been made small to be 1.5 mm square. A special processing is made to reduce the line loss.

A phase shifter of 4-bit s is composed of four groups of two transmission lines connected in serial and eight MEMS switches. For each group of lines, two switches are installed at the input and output to select one of two lines. In our project, mechanical switches on the basis of RF-MEMS technology are inevitable to accomplish a low loss instead of semiconductor switches due to high frequencies. In the actual phase shifter, MEMS switches are mounted on the transmission lines of LTCC technology, as shown in Fig.7. The size is 10 x 13 mm.

.

### 3.4 Control circuits

The control circuit consists of a Lab-View based control signal generator and locally distributed signal receivers which are integrated in the 3.5 μm high voltage CMOS technology, as shown in Fig.8. The location of a receiver is chosen out of a number of the receivers by a correspondent select line. The bit patterns for the electro-static actuator are serially transmitted, and are converted by the receiver to parallel patterns of 40-V open-drain signal to drive a MEMS switch.

## 4. System study results

Integration of the total APAA was studied. In the current design, multiple layers are used as shown in Fig.9. A layer is assigned to each function; antennas, MMIC and phase shifters, digital and control circuits, and power sources.

The method to test APAA is another important issue because many parameters should be changed and environmental effects should be eliminated. In our project, a near- field measurement are to be used. A special probe was designed and showed an excellent spatial resolution in the experiment, as shown in Fig.10.

## 5. Conclusions

The tentative goals fixed at the start of 2007 have been almost satisfied. The devices of antennas, MMICs, RF-MEMS switches, control circuits and assembled phase shifters were realized with significant progresses. Peripheral facilities such as measuring equipment are also being prepared. As the result of market survey, mobile terminals in satellite communications have been selected to system integration in the next year for an actual application.

## Acknowledgement

This work is supported by the research contract of Ministry of Internal Affairs and Communications. And the authors thank the project members for their devotion to this work.

## References

[1] T. Takano, S. Kawasaki, H. Toshiyoshi, H. Ikeda and Y. Kazama, “The R&D of Active Phased Array Antennas with Significant Cost Reduction and Usage Convenience”, ISAP07, 4B3-3, Niigata JAPAN, 2007.
[2] M. Okumura, Y. Kamata, T. Imura, K. Kumamaru and T. Takano,“Experimental Study on a Partially Driven Array with Simplified Dipole Elements”, a234-r142, ISAP06, November, Singapore, 2006.
[3] T. Imura, M. Okumura and T. Takano, “A Consideration of Arrangement of a Partially Driven Dipole Array Antenna”, Proceedings the 2007 IEICE Society Conference, B-1-185, Nagoya, March 2007.
[4] Y. Kazama, A. Sugawara, T. Takano and D. Radenamad, “Novel Phased Array Antenna with Elements of Conical Beam Patterns”, IEEE AP-S, 2008.
[5] S. Kawasaki, “Development of 5.8GHz High Power Active Integrated Antenna Arrays“, Proceedings of APMC2007, WE-P1-A1, Bangkok Thailand, December, 2007, pp. 3-6.
[6] S. Kawasaki, H. Seita, T. Suda, K. Takei, K. Nakajima, “32-Element High Power Active Integrated Phased Array Antennas Operating at 5.8GHz”, to be publuished in IEEE AP-S2008 Digest, San Diego, July 2008.
[7] D. Yamane, T. Yamamoto, K. Urayama, K. Yamashita, H. Toshiyoshi, and S. Kawasaki, "A Phase Shifter by LTCC Substrate with an RF-MEMS Switch," in Proc. 38th European Microwave Conference (EuMC 2008), Amsterdam, Netherlands, Oct. 27-31, 2008 (to be presented).

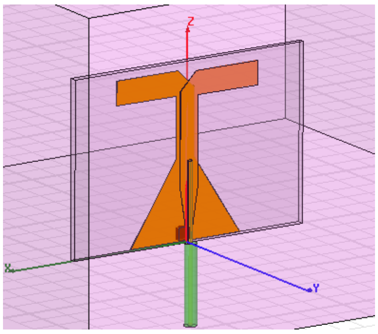
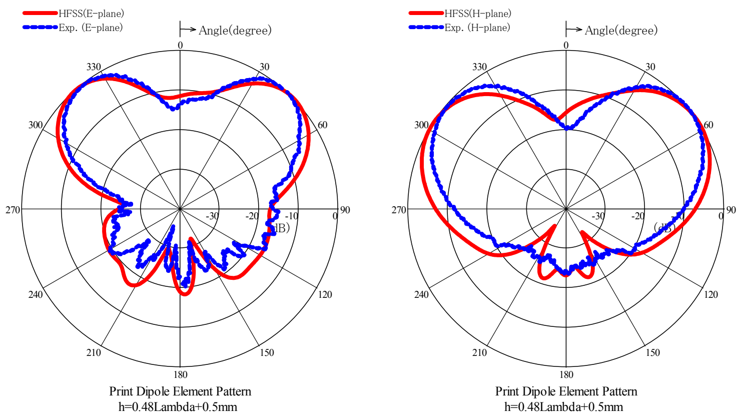


Fig. 1 An element antenna with a conical beam




(a) E-plane (b) H-plane

Fig. 2 Radiation patterns of the element antenna

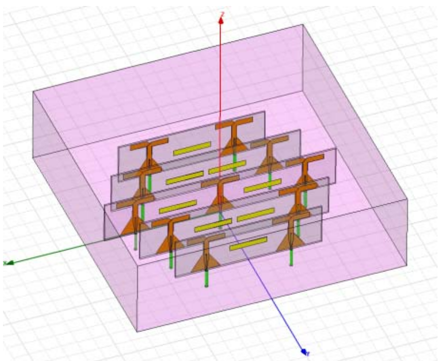


Fig. 3 Designed array antenna with partial drive technique.

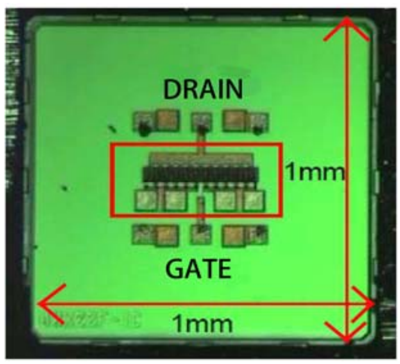



Fig.4 Outlook of a chip for HPA.

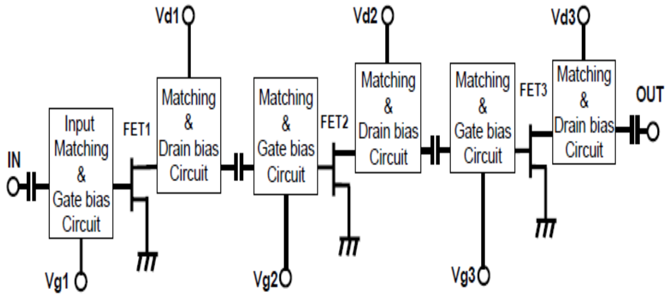



Fig.5 Block diagram of LNA.

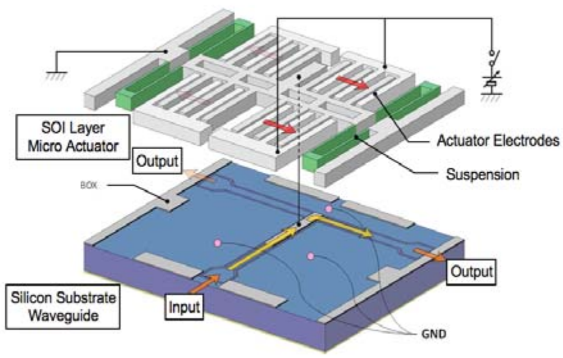



Fig.6 Proposed configuration of a MEMS switch

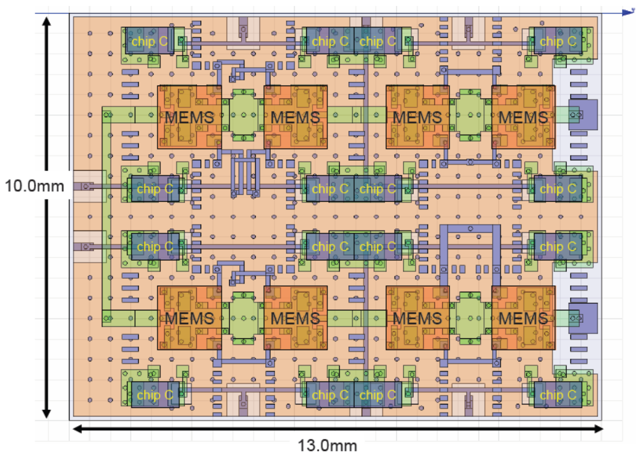



Fig.7 Outlook of a 4-bit phased shifter in K-band

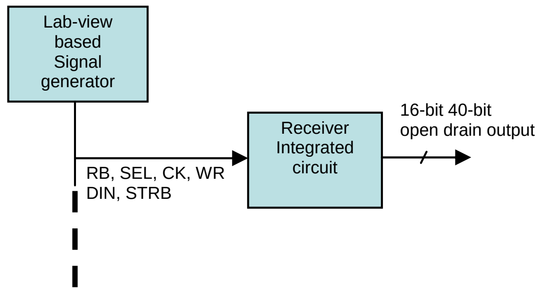



Fig.8 Configuration and signals of the control circuit.

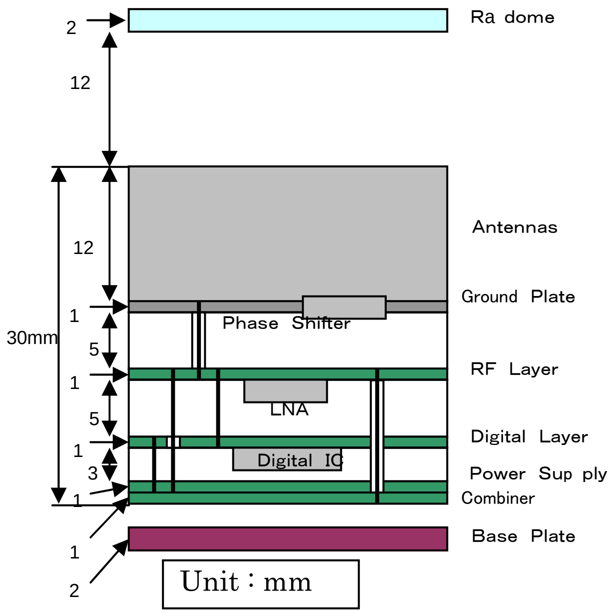



Fig.9 Concept of the multi-layered integration of APAA .

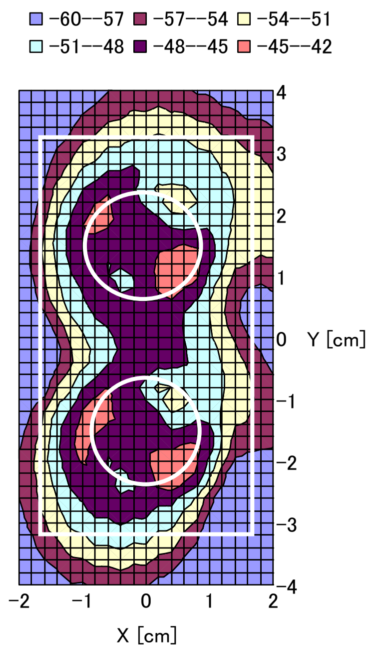



Fig.10 Experimental result of the near-field measurement